Pattern and Probe-Based Aberration Monitors for the Human Eye

e-beam lithography

E298A/EE290B

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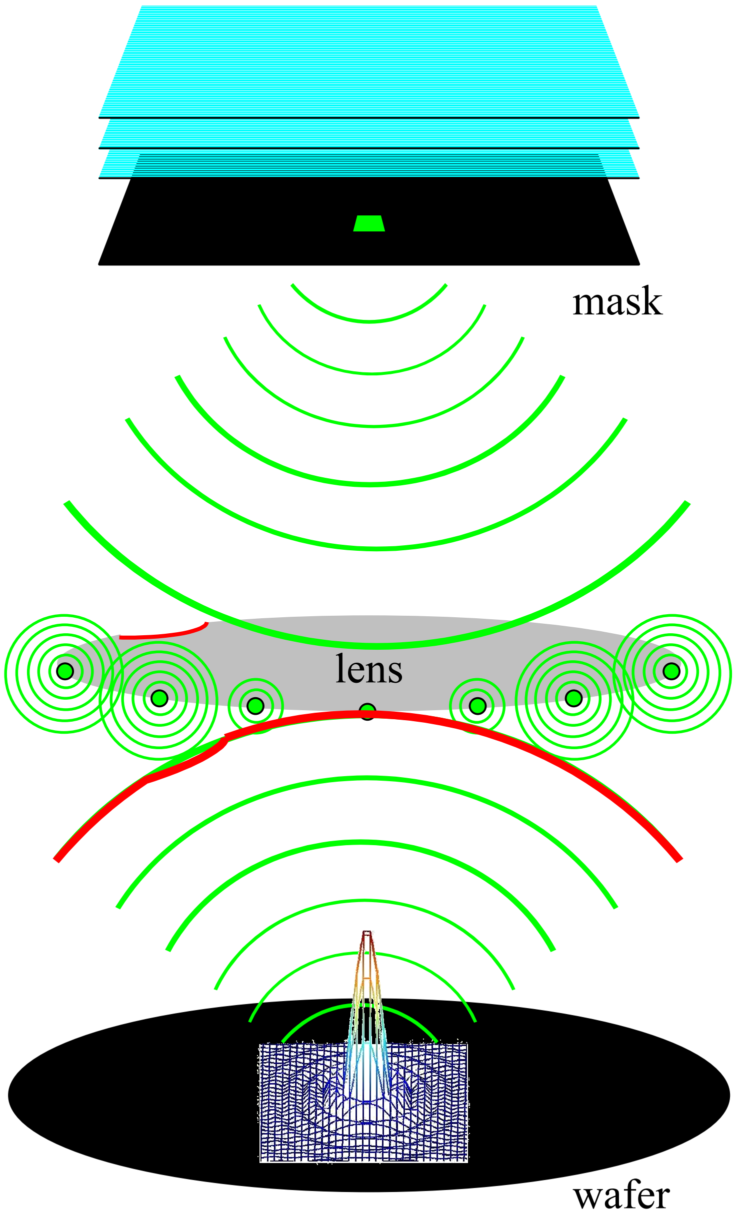
Outline

- Introduction to aberrations
- Pattern and probe-based aberration monitors
  - Sensitivity
- Application to aberrations in human eyes
- Process flow & results
- Proposed experimental setup
- Summary: Proposed new process

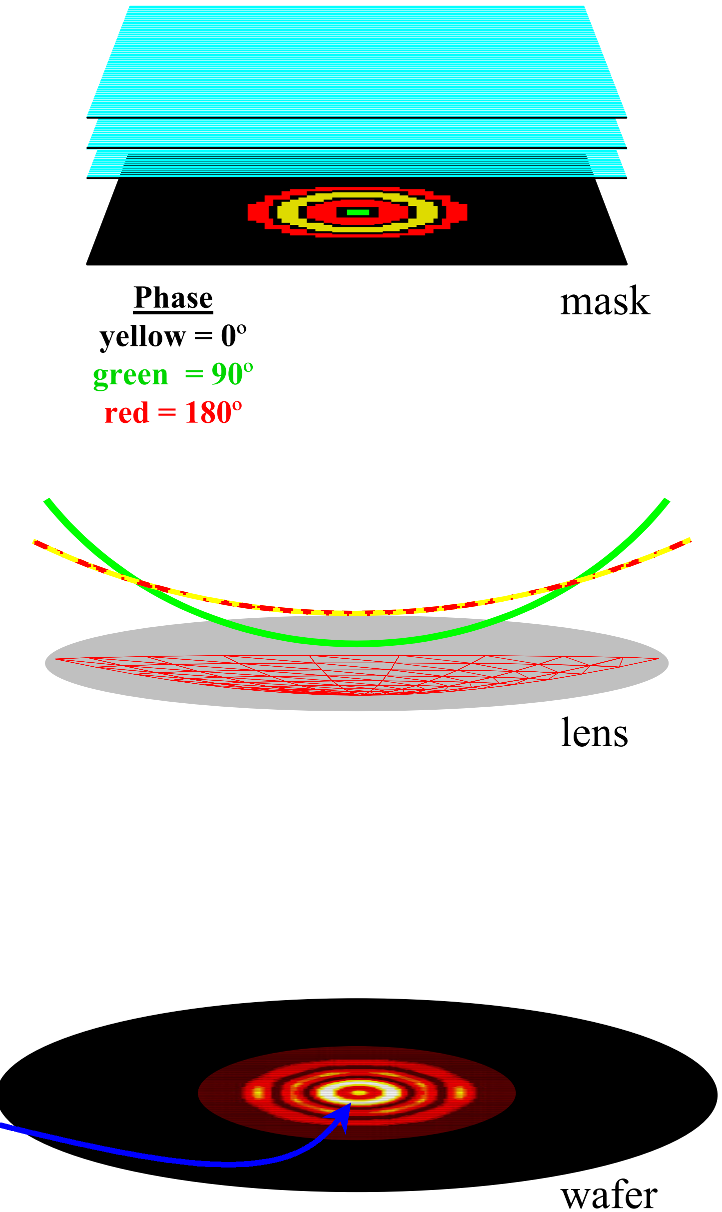
What is an aberration?

- Small opening in chrome fills entire pupil with scattered light
- Spherical wavefront incident upon lens
- Form & figure errors along w/ inhomogeneity of lens material results in deviation from sphericity upon exit
- Hecht: "…deviations in OPL b/w actual & ideal wavefronts…[μm], [nm], or [λ]."

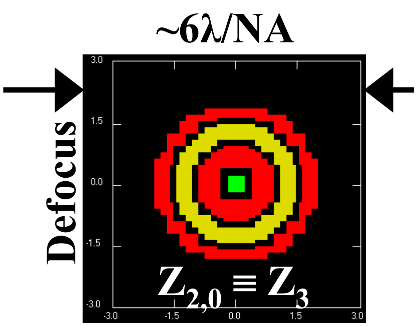


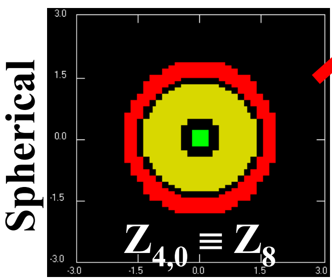
Aberrations Over a Circular Pupil (2-D)

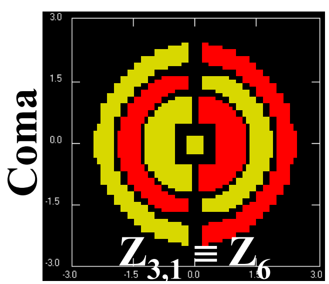
- Targets designed to **quantify individual Zernike aberrations** to **1/100 λ rms**
- Each target has a **probe** (0.4 λ/NA), surrounded by a **pattern** on the mask
- Optimum pattern is the Inverse Fourier Transform (IFT) of Zernike of interest
- **Even/odd** aberrations require **90º/0º** probe
- Light scattered by target rings interacts with aberrations in lens, spilling light into **center probe region** at image plane

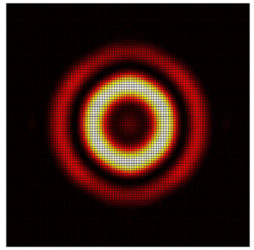


Target Sensitivity and Orthogonality

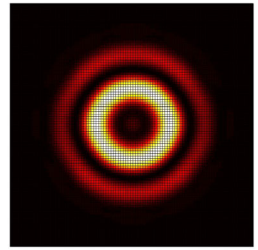




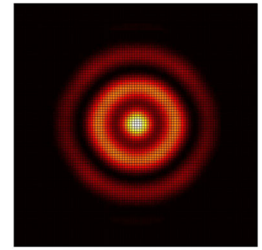




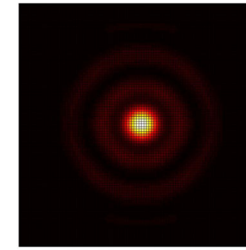
w/ 0 aberration



w/ 5/100 λ rms of defocus (Z3)



w/ 5/100 λ rms of spherical aberration (Z8)



w/ 11/100 λ rms of spherical aberration (Z8)

<u>**Phase**</u>

yellow = 0°

green = 90°

red = 180°

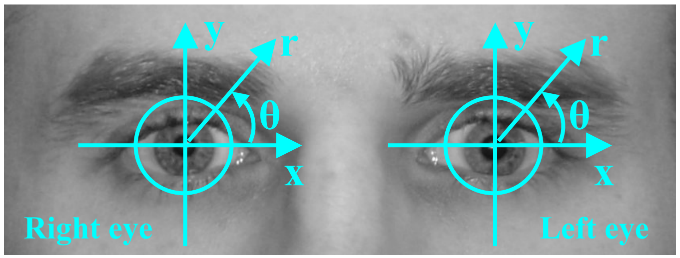
0.4 λ/NA probe

σ = 0.1	**Targets**				
δ-peak with 0.01 λ rms of	**Defocus**	**Spherical**	**HO Spherical**	**Coma**	**HO Coma**
No Aberration (peak value)	0.933	0.242	0.207	0.555	0.222
Defocus	**+0.220**	-0.034	-0.021	<+0.01	<|-0.01|
Spherical	<+0.01	**+0.256**	-0.056	<+0.01	<+0.01
HO Spherical	-0.084	-0.063	**+0.299**	<+0.01	<+0.01
Coma	+0.020	<+0.01	<+0.01	**+0.299**	-0.038
HO Coma	<+0.01	<+0.01	<+0.01	<|-0.01|	**+0.249**

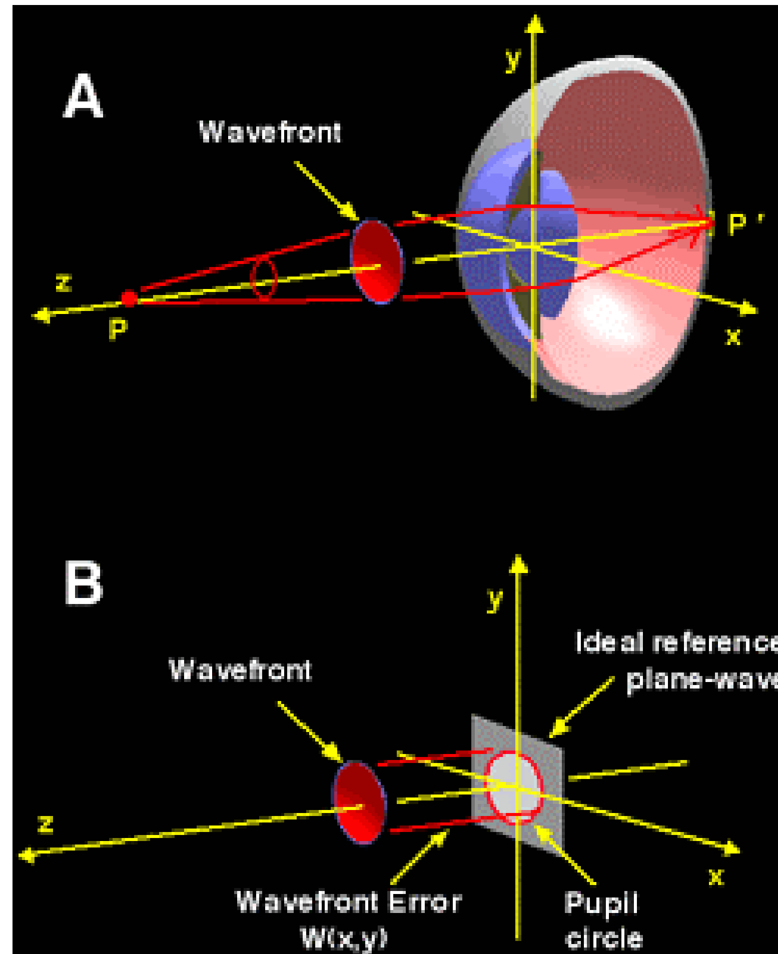
VSIA-99 Standards Taskforce (OSA)

Vision Science and it's Applications
Optical Society of America

Clinician's View of Patient



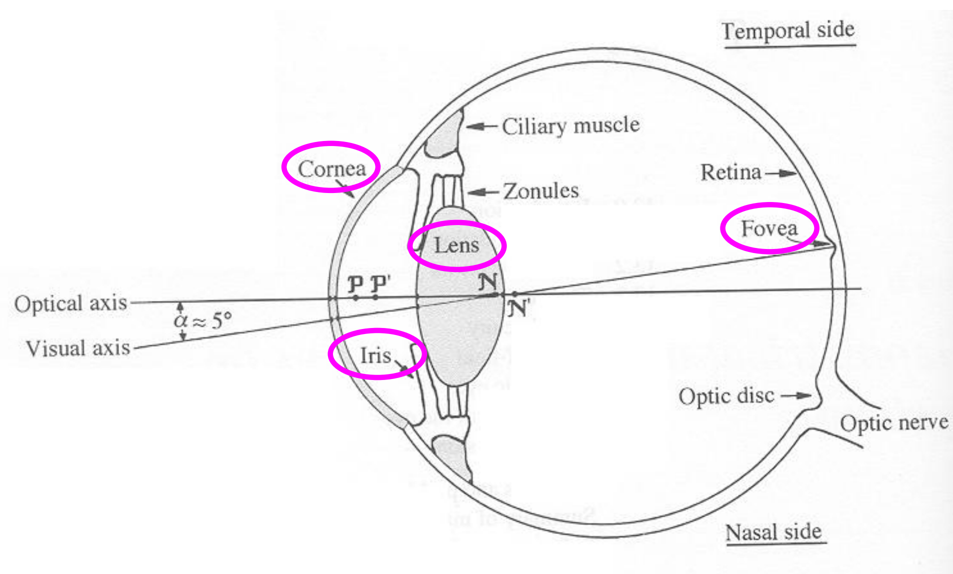
- Coordinate system
- Resolved to use Zernikes
- Give aberrations wrt entrance pupil b/c image space is generally inaccessible



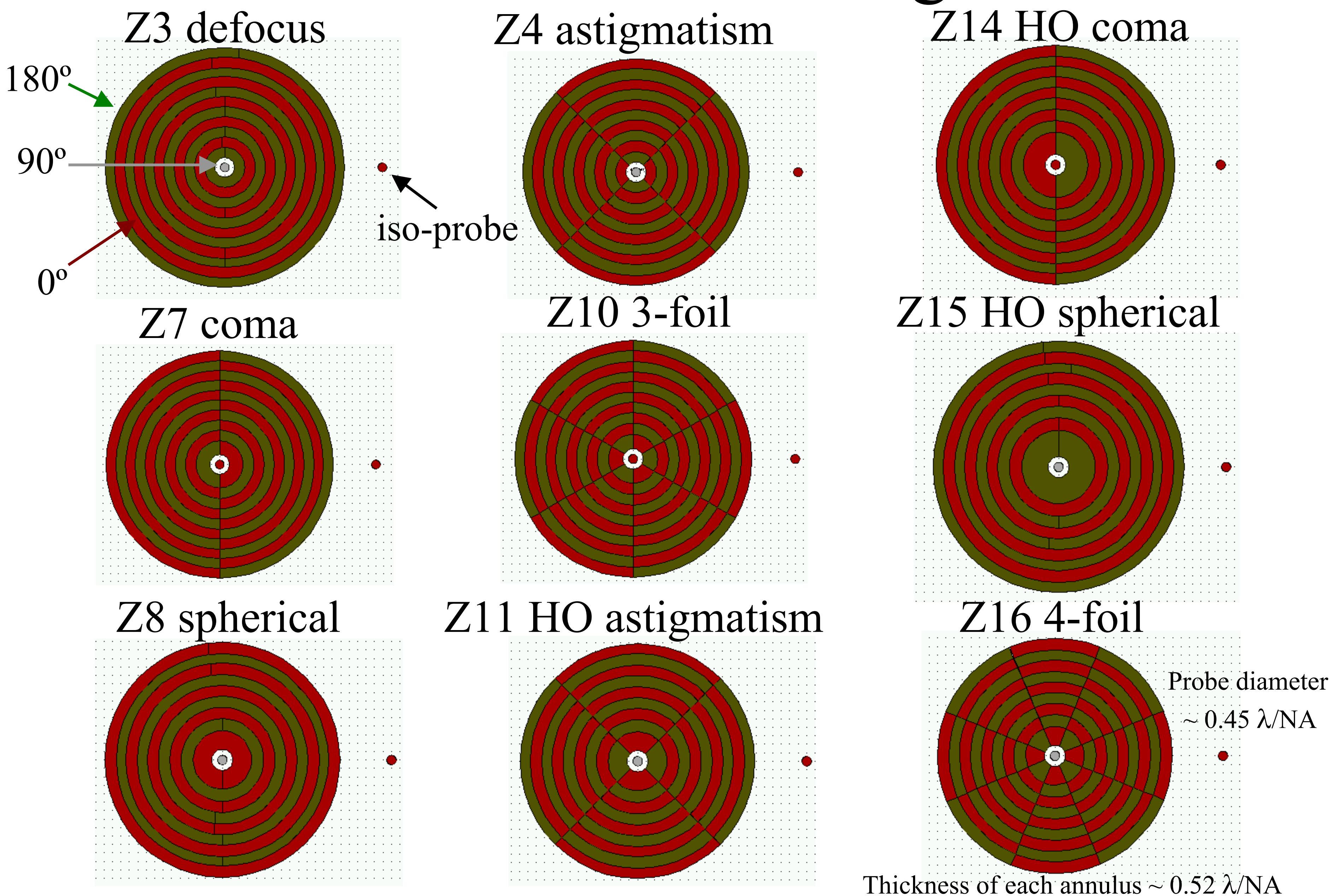
Biology Lesson: The Human Eye

- Highly complex imaging system
- Decentered optical system with non-rotationally symmetric components
  - cornea, aqueous humor, iris, crystalline lens, vitreous humor retina, rods & cones, fovea (macula)
- Varying “film grain”
- Foveola has the highest concentration of cones & covers just < 1º in angular extent (0.35mm diam.)

- We rotate our eye so that the object of interest images to the foveola
- Ability to see fine details most strongly affected by aberrations at the foveola (coma dominates) VSIA-99

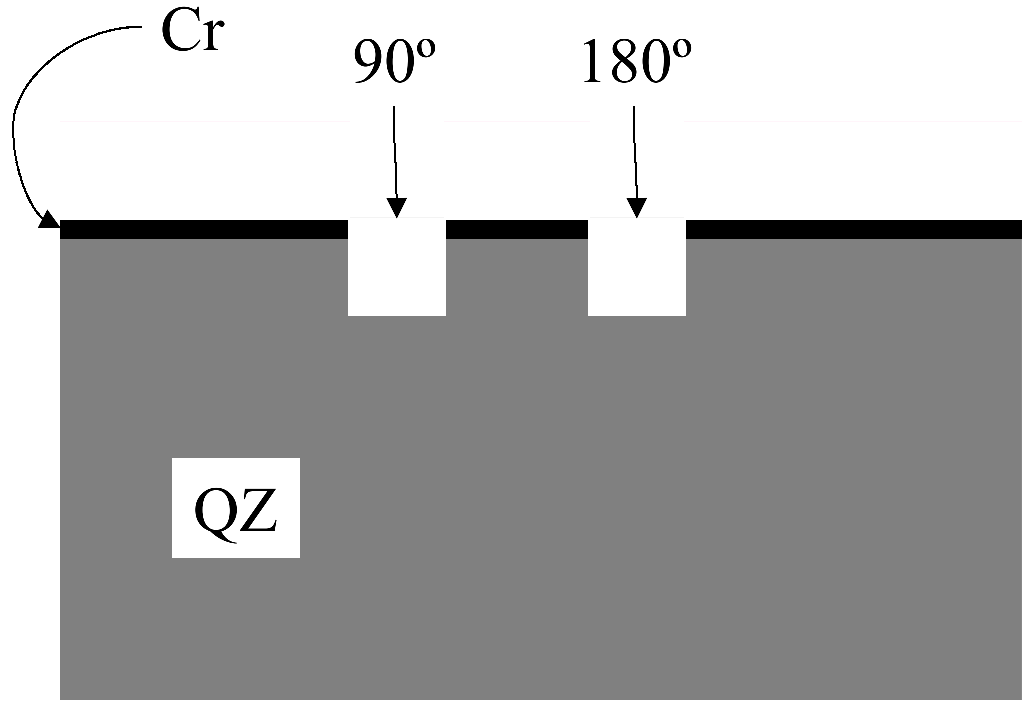


GDS of Zernike Targets



Simplified 3 Phase Mask Flow 1

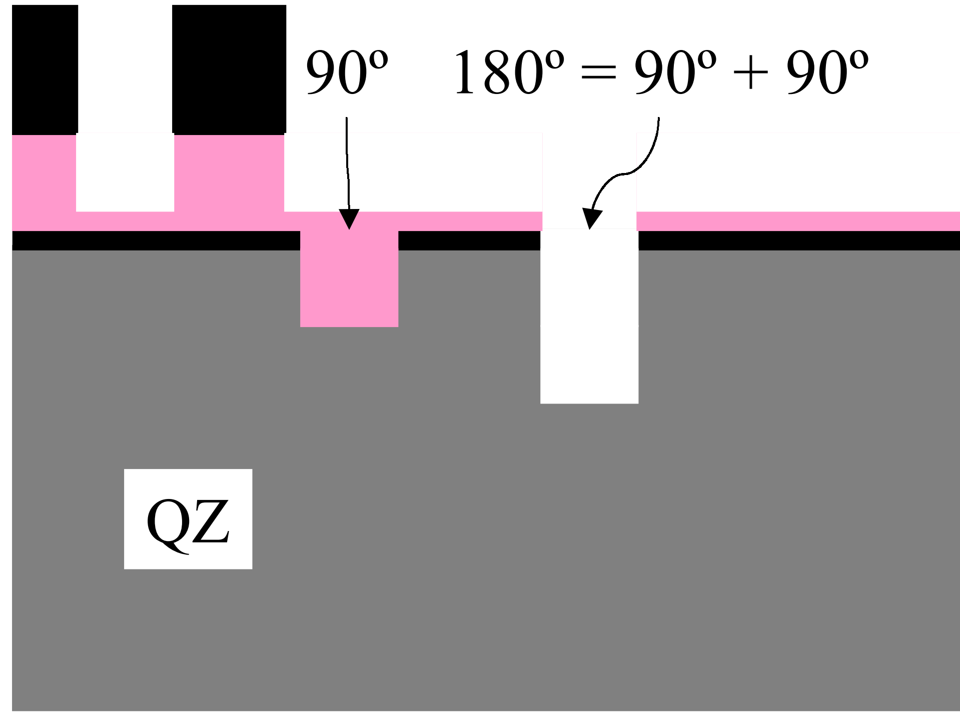
- 4” Hoya wafer
- 1030Å cr on quartz
- 0.5µm KRS-XE 11.6% (1000rpm)
- 4 different doses
- **Step 1:** open chrome for 90º (346µm) and 180º (692µm) phase shift regions.
- Cr etch
- Strip resist & use cr as etch mask
- QZ etch 90º (~356µm)

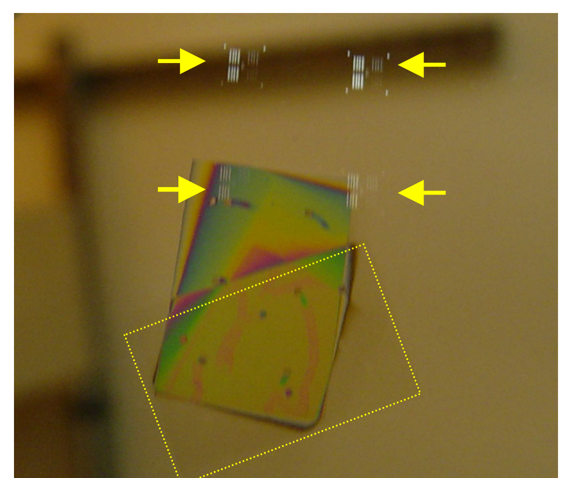


- QZ etch: 5 + 8 + 2 + ½ + ½ min. = 16 min.
- Cr + QZ etch = 230, 390, 439, 444, 456nm

Simplified 3 Phase Mask Flow 2

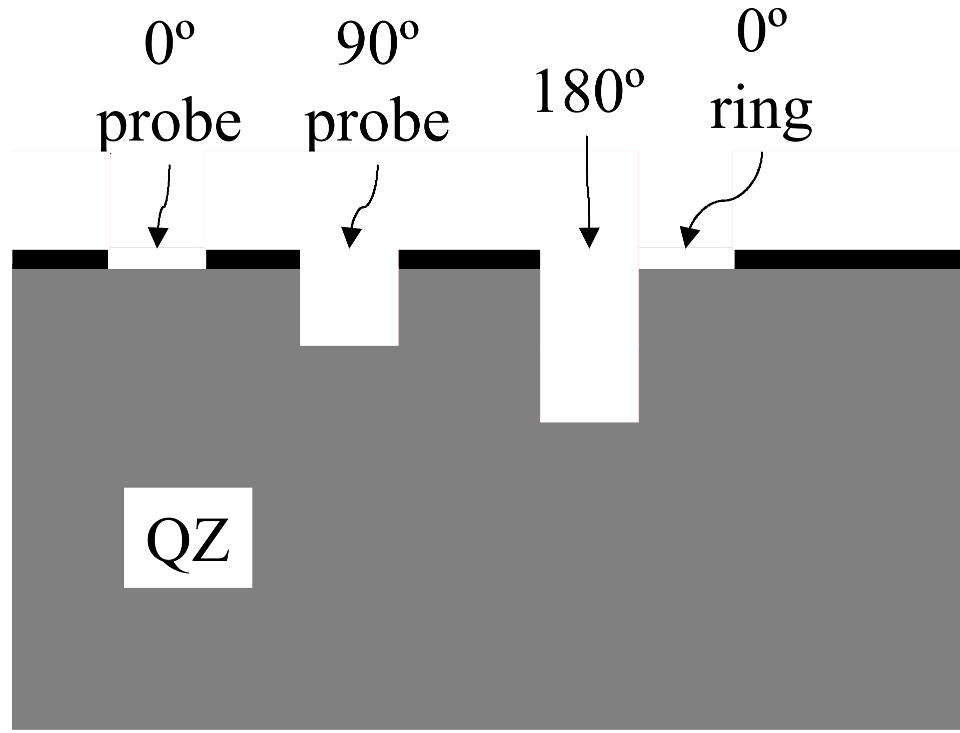
- **Step 2:** open resist for 180º (+346µm, ttl. = 692µm) phase shift regions.
- Use chip with windows to measure resist etching
- Windows moved (*!*)
- QZ etch _*+23 min.*_ (*!*) +90º (ttl. w/o cr ~ 833µm)
- Appears to have etched away all resist as well, possibly exposing the 90º probes to overetching

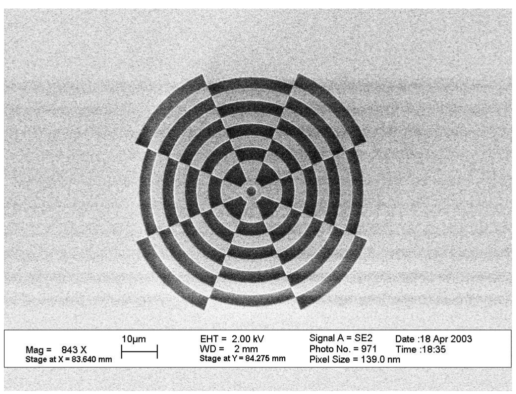


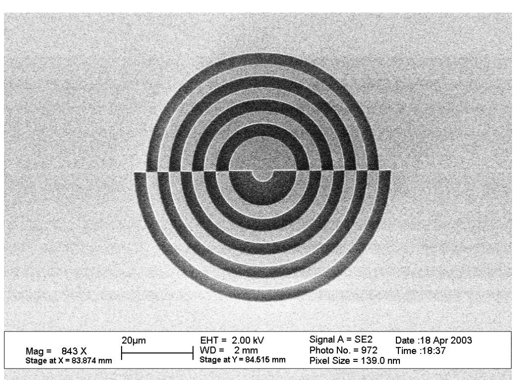


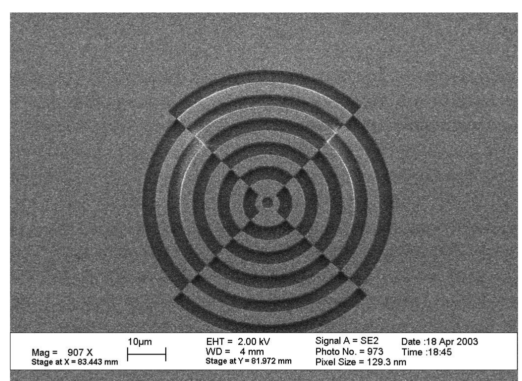
Simplified 3 Phase Mask Flow 3

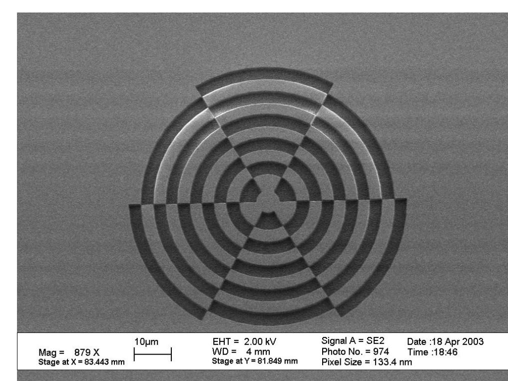
- **Step 3:** open cr for 0º rings & probes
- Cr etch



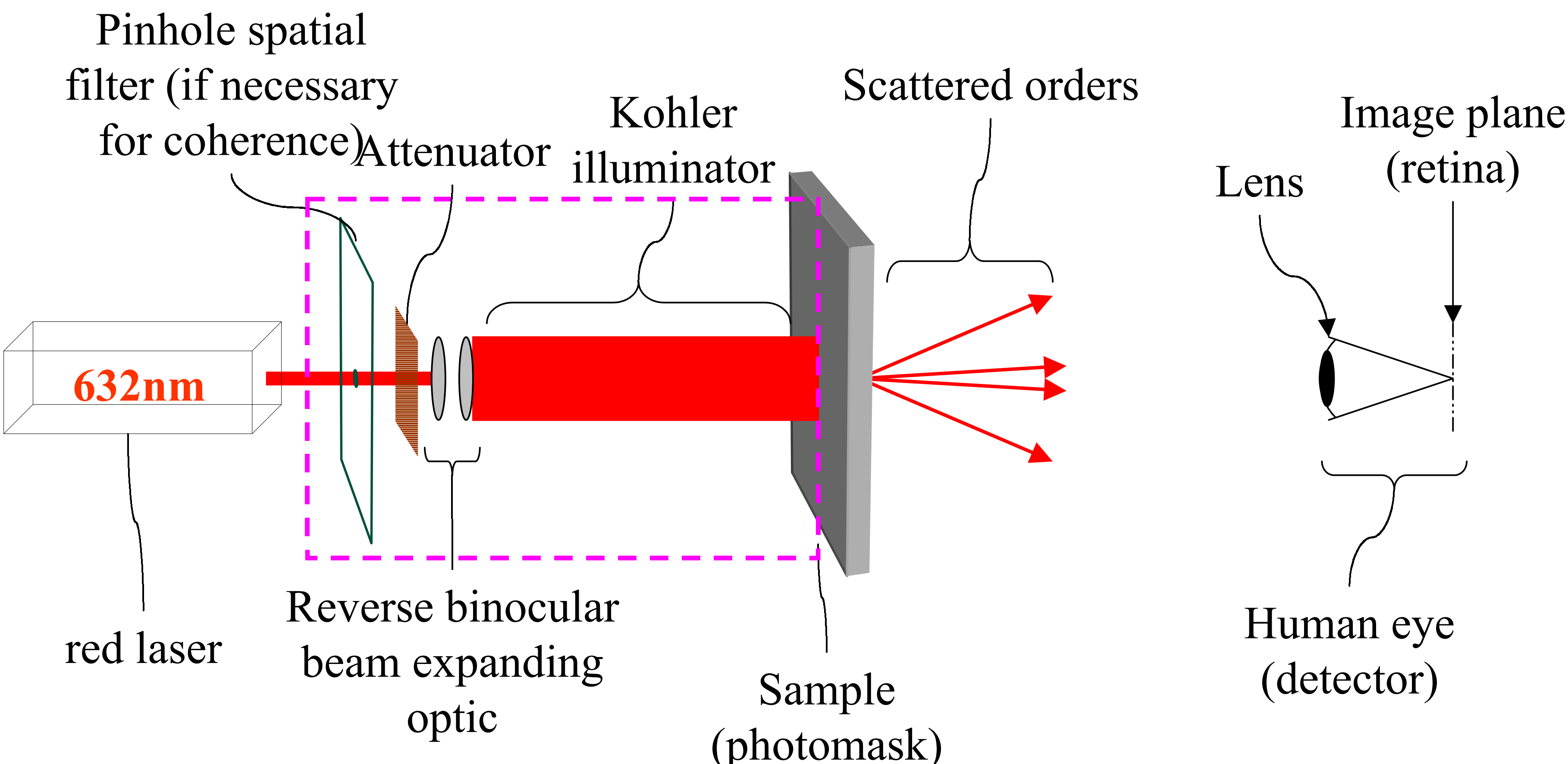








Proposed Experimental Setup 1



Measures aberrations in human eye

Summary

- Processing on three phase "mask" for the detection of Zernike aberrations in the human eye taken to final stage.
- Second quartz etch was too deep, but would have been correct if appropriate time used.
- New process: open 0º regions in cr, then 90 º & 180º regions (90º QZ etch), open 180º regions (+90º QZ etch) (still requires 3 lithos. & can't use cr as hard mask)

References

- Thibos LN. Wavefront data reporting and terminology. J Refract Surg (2001) 17; S578-583
- J Refract Surg 2002 Sep-Oct;18(5):S652-60 Standards for reporting the optical aberrations of eyes. Thibos LN, Applegate RA, Schwiegerling JT, Webb R; VSIA Standards Taskforce Members. Vision science and its applications.
- G. Smith & D. Atchison, The Eye and Visual Optical Instruments, Cambridge University Press, 1997.

THE END